

METHOD OF MANUFACTURING A TOP INSULATING LAYER FOR A SONOS-TYPE DEVICE

TECHNICAL FIELD

5 The present invention relates generally to dielectrics for field effect semiconductor devices, and more particularly to dielectrics for SONOS-type nonvolatile semiconductor devices.

BACKGROUND OF THE INVENTION

10 As is well known, semiconductor devices can include an insulated gate field effect transistor (IGFET) type device. IGFET-type devices typically include a transistor gate separated from a channel region by a dielectric. A potential applied to a gate can then be varied to alter channel conductivity.

15 While many IGFET type devices are volatile (e.g., conventional metal-oxide-semiconductor FETs), nonvolatile devices may also include IGFET-like approaches. One conventional nonvolatile device can be a floating gate electrically erasable programmable read only memory (EEPROM). A floating gate EEPROM can include a floating gate electrode situated between a control gate and a channel. Charge, including electrons and/or “holes” may be stored in a floating gate electrode. Such a charge may alter a threshold
20 voltage of a resulting nonvolatile IGFET-type device. As will be noted below, a drawback to any floating gate device can be higher programming and/or erase voltages with respect to other nonvolatile approaches.

25 Another nonvolatile IGFET type device can include a dielectric interface to store (i.e., trap) charge. For example, devices have been proposed that include a metal gate formed over a dielectric of silicon nitride and silicon dioxide. Such devices have been referred to as

metal-nitride-oxide-semiconductor (MNOS) devices. A drawback to many MNOS devices has been lack of charge retention and/or uniformity of programming.

A third type of nonvolatile device may include one or more dielectric layers for storing charge. Such devices may be referred to generally as silicon-oxide-nitride-oxide-silicon (SONOS) type devices. One very basic type of SONOS device may include a polycrystalline silicon ("polysilicon") gate formed over a dielectric layer that includes a silicon nitride layer sandwiched between silicon dioxide layers.

SONOS devices can have lower programming voltages than other conventional nonvolatile devices, such as some types of floating gate devices. In addition, the SONOS fabrication process can be compatible with standard complementary metal oxide semiconductor (CMOS) process technology. To maintain this compatibility, SONOS devices may be scaled along with other transistors used in the process. The ability of SONOS devices to maintain performance and reliability as they are scaled can be an important feature.

To better understand the formation of SONOS devices, a conventional way of forming a SONOS device is set forth in FIGS. 6 and 7. FIG. 6 is a flowchart illustrating several process steps involved in creating an integrated circuit containing SONOS devices. FIGS. 7A-7H set forth a number of side cross-sectional views of a portion of an integrated circuit containing SONOS devices following the various process steps described in FIG. 6.

The conventional process described in FIG. 6 is designated by the general reference character **600**. A conventional process **600** may include the steps of growing a tunnel oxide **602**, depositing a silicon nitride layer **604**, depositing a top oxide layer **606**, depositing a polysilicon gate layer **608**, forming a gate mask **610**, etching gates **612**, and depositing and

etching a spacer layer **614**.

Referring to FIG **7A**, a side cross-sectional view of a portion of an integrated circuit prior to the beginning of a conventional process **600** is shown. The integrated circuit portion includes a substrate **700**, and may include isolation regions **702** formed by prior process
5 steps. As an example, isolation regions **702** may be formed by various conventional isolation processes including but not limited to shallow trench isolation (STI) or the local oxidation of silicon (LOCOS).

It is noted that a substrate **700** may also include various impurity regions, form by ion implantation and/or diffusion methods. As but a few examples, n-type wells may be formed
10 in a p-type substrate (or vice versa), or p-type wells may be formed within n-type wells (or vice versa). An important aspect of forming diffusion regions can be controlling the depth and/or lateral extents of such regions. Subjecting diffusion regions to temperature cycles following their initial formation can result in the dopants of the diffusion region diffusing
15 “abruptness” of a dopant concentration at the edge of a p-n junction. Too many temperature cycles may thus result in adverse transistor operation due to junction breakdown or “punch-through” current, to name just two examples. Consequently, the fabrication process of an integrated circuit may emphasize minimizing a device’s exposure to temperature cycles (keeping as small a “thermal budget” as possible).

20 Referring again to FIG. 6, a conventional process **600** may begin by growing a tunnel oxide (step **602**). A portion of an integrated circuit following step **602** is set forth in FIG. **7B**. Referring to FIG. **7B**, a portion of an integrated circuit includes a tunnel oxide **704** on a substrate **700**. A tunnel oxide **704** is generally very thin and may be on the order of 15

angstroms (15Å) thick.

A conventional process **600** can continue by depositing a silicon nitride layer (step **604**). A portion of an integrated circuit following step **604** is set forth in FIG. **7C**. Referring to FIG. **7C**, an integrated circuit portion now includes a nitride layer **706** deposited over a tunnel oxide **704**. A nitride layer **706** generally consists of silicon nitride (Si_3N_4), and may be 80-100 Å thick.

A conventional process **600** can continue by depositing a top oxide layer (step **606**). Referring to FIG. **7D**, an example of a portion of an integrated circuit following step **606** is set forth. A substrate **700** now includes a tunnel oxide **704**, a nitride layer **706** and a top oxide layer **708**. A top oxide layer **708** can be conventionally formed by chemical vapor deposition (CVD) and may generally be 30-40 Å thick.

A conventional process **600** can continue by depositing a polysilicon gate layer (step **608**). An example of a portion of an integrated circuit following step **608** is set forth in FIG. **7E**. Referring to FIG. **7E**, a polysilicon gate layer **710** has been deposited on a top oxide layer **708**. As also shown in FIG. **7E**, a gate protection insulator may also be formed over polysilicon gate layer **710**.

At this point, in the conventional process **600**, five layers of a SONOS device have been created. The silicon-oxide-nitride-oxide-silicon layers correspond to the substrate **700**, tunnel oxide layer **704**, nitride layer **706**, top oxide layer **708**, and polysilicon gate layer **710**, respectively.

The conventional process **600** may continue with lithography and etch steps to isolate and form SONOS devices. A gate mask may first be formed (step **610**). An example of a portion of an integrated circuit following step **610** is set forth in FIG **7F**. A gate mask

material **712** has been deposited and patterned using any of various lithographic techniques. The gate mask material **712** may generally consist of a photoresist material.

Following the formation of a gate mask (step **610**), gates can be etched (step **612**). Referring to FIG. **7G**, a portion of an integrated circuit following step **612** is set forth. A suitable etch process has been applied to remove portions of the tunnel oxide **704**, nitride layer **706**, top oxide layer **708**, and polysilicon gate layer **710** that are not covered by gate mask material **712**. In this manner, SONOS devices are formed and isolated on the substrate **700**.

The conventional process **600** can continue by depositing and etching a spacer layer (step **614**). An example of a portion of an integrated circuit following step **614** is set forth in FIG. **7H**. Referring to FIG. **7H**, a spacer layer **714** has been formed that surrounds and isolates the SONOS gates. The spacer layer **714** may consist of silicon dioxide. Note that in FIG. **7H**, the gate mask layer **712** has been removed by suitable process means.

While the conventional process described may produce an integrated circuit containing SONOS devices of reasonable quality and performance, certain aspects of the process are critical in maintaining device performance and reliability as the SONOS devices are scaled to realize lower programming voltages and to maintain compatibility with CMOS process technology.

A top oxide layer **708** may suffer from certain drawbacks as a SONOS device is scaled down. A top oxide layer **708** can function to isolate the transfer of charge between a nitride storage layer **706** and a polysilicon gate layer **710**, permitting scaling of a nitride layer **706** to realize low programming voltages. Consequently, the lower the quality of a top oxide layer **708**, the more charge that may leak through such a layer. For this reason, quality of top

oxide layer **708** can be an important feature in a SONOS-type device.

An oxide layer, such as a SONOS-type device top oxide layer, can generally be formed by either thermal oxidation or by chemical vapor deposition (CVD). Thermal oxides, which can be grown from a base material of silicon nitride and/or silicon oxynitride, can be higher quality oxides as they can be denser and/or less porous and/or more reliably formed. Thus, thermal oxides can be better insulators. A drawback to thermal oxides can be the typically large thermal budget required to form them.

For a conventional SONOS process, the thermal budget required for a thermally grown top oxide layer may be about 1000°C to 1100°C for 3 to 4 hours, because the oxidation rate of silicon nitride and/or silicon oxynitride can be considerably slower than the oxidation of other materials, such as silicon. This large thermal budget may result in an unacceptable diffusion of channel and well implant dopants.

While conventional oxidation may provide higher quality oxide layers, such processes may result in an overall thermal budget that is unacceptably high. Consequently, conventional approaches may form top oxide layers by a deposition process. Conventional deposition processes typically include a gaseous reaction that can result in a top oxide layer being formed over a nitride and/or oxynitride layer. Thus, unlike oxidation steps, deposition processes are not necessarily dependent upon the underlying material. Deposition process may also have considerably smaller thermal budgets. For example, a conventional oxide deposition process may occur at a temperature of about 750 °C for about 3-4 minutes. Deposited oxides are therefore typically used for the top oxide layer **708** in a conventional SONOS process.

Limitations of a deposited top oxide layer **708** may include poor quality because it is

not as dense as a thermal oxide, and/or poor uniformity of thickness, and/or a rough interface between the nitride layer 706 and the top oxide layer 708. A rough interface may include a large number of interface traps. These limitations limit device performance and/or reliability, and/or the ability to scale SONOS devices for low programming voltages.

5 Various oxidation methods directed to other structures of a semiconductor device are known. In particular, surfaces of a shallow trench isolation (STI) trench are known to be oxidized by thermally reacting hydrogen (H₂) and oxygen (O₂) on a substrate surface (i.e., *in situ* steam generation). Such an oxidation may take place prior to filling the STI trench with an isolation material. Further, such a substrate may still contain a trench etch mask of nitride
10 formed over a sacrificial oxide layer.

In light of the limitations of the conventional process set forth above, it would be desirable to form a top insulating layer for a SONOS device that has the high quality of a thermally grown oxide without the large thermal budget that is conventionally required.

15 SUMMARY OF THE INVENTION

According to one embodiment of the present invention, a method may include growing a thermal oxide by reacting hydrogen and oxygen on a wafer surface, and forming a conductive gate over the oxide.

20 According to one aspect of the embodiment, the conductive gate material may be polysilicon.

According to another embodiment, a method may include forming a tunnel dielectric, forming a charge storing dielectric layer, forming a top oxide layer, forming a gate layer, forming a gate etch mask, etching to form gate stacks, and forming insulating sidewalls.

According to one aspect of this embodiment, the charge storing dielectric layer may include silicon nitride.

According to another aspect of this embodiment, the method may be used to create a SONOS-type nonvolatile semiconductor storage device.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing a method of manufacturing a nonvolatile semiconductor device according to one embodiment.

FIGS. 2 A, 2B, and 2C are side cross-sectional views showing the method of FIG. 1.

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FIG. 3 is a block diagram showing a method of manufacturing a nonvolatile semiconductor device according to another embodiment.

FIGS. 4A to 4H are side cross-sectional views showing the method of FIG. 3.

FIG. 5 is a diagram of a wafer processing tool that may be used in the present invention.

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FIG. 6 is a block diagram showing a conventional method of manufacturing a nonvolatile semiconductor device.

FIGS. 7A to 7G are side cross-sectional views showing the conventional method of FIG. 6.

DETAILED DESCRIPTION OF THE EMBODIMENTS

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Various embodiments of the present invention will now be discussed in conjunction with a number of figures. The embodiments set forth approaches to forming a thermal oxide on a charge storing dielectric layer. In particular embodiments, these layers may be used to form a SONOS-type nonvolatile semiconductor storage device.

Referring now to FIG. 1, a method of forming a series of semiconductor device layers is set forth in a block diagram designated by the general reference character **100**. The first embodiment **100** may include the steps of forming an oxide layer from a charge storing dielectric layer **102** and depositing a conductive gate layer **104**. FIGS. **2A-2C** set forth a number of cross-sectional views of a portion of a semiconductor device corresponding to the process steps described in FIG. **1**.

Referring to FIG. **2A**, a portion of a semiconductor device includes a tunneling dielectric **204** and a charge storing dielectric layer **206** on a semiconductor substrate **200**. A tunneling dielectric may include silicon dioxide, and a charge storing dielectric may include silicon nitride, silicon oxynitride, and/or silicon-rich silicon nitride, as but a few examples. A tunneling dielectric may be formed by conventional means, such as oxidizing a silicon substrate. A charge storing dielectric may be formed by chemical vapor deposition methods.

A method according a first embodiment may include forming an oxide layer for a charge storing dielectric layer (step **102**). Referring to FIG. **2B** an oxide layer **208** has been formed over a charge storing dielectric layer **206**.

In a preferred embodiment, an oxide layer **208** is thermally grown from a charge storing dielectric layer **206** by reacting hydrogen and oxygen on the wafer surface. This reaction may occur at temperatures in the range of 900°C to 1100°C. In this approach, the oxide layer **208** may be formed in about one minute and may grow an oxide layer about 30-40 Angstroms thick. The formation of a thermal oxide in this manner may also be referred to as In Situ Steam Generation (ISSG).

In this way, a high quality thermal oxide may be grown in a shorter time than conventional oxidation approaches. As a result, such a step may provide for a lower thermal

budget than conventional approaches that may grow an oxide layer according to other methods.

According to a first embodiment, a method may also include depositing a conductive gate layer (step **104**). Referring to FIG. **2C**, a semiconductor device portion is shown to include a gate layer **210** that has been formed over an oxide layer **208**. A gate layer **210** may include polysilicon, as but one example.

In this way, a first embodiment may form a top oxide layer for charge storing dielectric that can have a higher quality than deposition approaches, but with a thermal budget that may be lower than conventional oxidation approaches.

A second embodiment of the present invention will now be described. \

The second embodiment includes a method for forming an ISSG oxide layer on an integrated circuit that may include insulated gate field effect transistor (IGFET) type devices. One example of an IGFET type device can be a SONOS-type nonvolatile semiconductor storage device.

A flow diagram is set forth in FIG. **3** that describes a second embodiment of the present invention. A second embodiment is designated by the general reference character **300**, and may include the steps of growing a tunnel oxide **302**, depositing a nitride layer **304**, forming an ISSG top oxide layer **306**, depositing a polysilicon gate layer **308**, forming a gate mask **310**, etching gates **312**, and depositing and etching a spacer layer **314**. FIGS. **4A-4H** set forth a number of side cross-sectional views of a portion of an integrated circuit containing SONOS semiconductor devices following the various process steps described in FIG. **3**.

Referring to FIG **4A**, a side cross-sectional view of a portion of an integrated circuit

prior to the start of the second embodiment process **300** is shown. The integrated circuit portion includes a substrate **400**, and may include an isolation region **402** formed by prior conventional process steps. In addition, as noted in conjunction with the first embodiment, a substrate may include impurity regions, such as wells and/or channel regions.

5 The second embodiment **300** may begin by growing a tunnel oxide layer (step **302**). A portion of an integrated circuit following step **302** is set forth in FIG. **4B**. Referring to FIG. **4B**, a portion of an integrated circuit includes a tunnel oxide **404** on a substrate **400**. A tunnel oxide **404** can be generally very thin with respect to other device layers, and may be on the order of 15 Å thick. In one very particular arrangement, a tunnel oxide may be grown
10 by placing a wafer into a rapid thermal oxidation (RTO) chamber. A dry oxidation process may form a tunnel oxide of thermally grown silicon dioxide.

 A second embodiment **300** can continue by depositing a nitride layer (step **304**). A portion of an integrated circuit following step **304** is set forth in FIG. **4C**. Referring now to FIG. **4C**, an integrated circuit portion now includes a nitride layer **406** deposited over a
15 tunnel oxide **404**. A nitride layer **406** may include silicon nitride (Si_3N_4), silicon oxynitride, and/or silicon-rich nitride, in one or more layers. Silicon-rich nitride may include silicon nitride having greater than stoichiometric ratios of silicon to nitride. In one arrangement, a nitride layer **406** may be 80-100 Å, as but one example. In one very particular example, a nitride layer may be formed by transferring a wafer from an RTO chamber into a low
20 pressure chemical vapor deposition chamber (LPCVD). Silicon nitride (or a similar such material) may then be formed with low pressure chemical vapor deposition techniques. Base materials of an LPCVD process may include ammonia (NH_3), dichlorosilane (DCS), and/or nitrous oxide (N_2O).

A second embodiment **300** can continue by forming an ISSG top oxide layer (step **306**) by reacting hydrogen and oxygen on the wafer surface. Referring to FIG. **4D**, an example of a portion of an integrated circuit following step **306** is set forth. A substrate **400** now includes a tunnel oxide **404**, a nitride layer **406**, and an ISSG top oxide layer **408**.

5 An ISSG top oxide layer **408** may be formed by reacting hydrogen (H_2) and oxygen (O_2) on a wafer at a temperature in the range of 900 °C to 1100 °C. Such a reaction may occur for about 1 minute in order to form an ISSG top oxide layer **408** of about 30-40 Å. A resulting thermally grown oxide according to the present invention may therefore be created with a very small thermal budget relative to conventional oxidation approaches. In one very particular approach, an ISSG top oxide layer **408** may be formed by transferring a wafer from
10 an LPCVD chamber used to form a silicon nitride layer, into an RTO chamber used to form a tunnel dielectric layer. The wafer may then be heated to 900 °C to 1100 °C with H_2 and oxygen O_2 in the chamber, or introduced into the chamber.

In this way, a high-quality thermal oxide may be achieved without unacceptable
15 diffusion of channel and/or well implant dopants.

An ISSG oxide layer **408** can be denser and of higher quality than a deposited oxide and/or more uniform. In addition, since an ISSG oxide layer **408** can be grown from a charge storing dielectric layer **406**, an interface is not necessarily at the original charge storing dielectric surface, but rather within the charge storing dielectric layer **406**.
20 Consequently, a resulting interface can be smoother than an interface created with conventional deposition techniques. In addition, such an interface may have less interface traps than conventional approaches, which may result in a higher performance SONOS device that may be scaled to lower programming voltages and yet maintain compatibility

with a conventional CMOS process.

Of course, as noted above, unlike conventional approaches for forming a top dielectric layer, an ISSG oxide layer may have a smaller thermal budget than conventional deposition techniques.

5 A method according to a second embodiment **300** can continue by depositing a polysilicon gate layer (step **308**). An example of a portion of an integrated circuit following step **308** is set forth in FIG. **4E**. Referring to FIG. **4E**, a polysilicon gate layer **410** has been deposited on an ISSG top oxide layer **408**. As also shown in FIG. **4E**, a gate protection insulator **411** may be formed over a polysilicon gate layer **410**. A gate protection insulator
10 **411** may include silicon nitride, preferably silicon oxynitride, even more preferably silicon oxide.

The second embodiment **300** may continue with lithography and etch steps to isolate and form SONOS devices. A gate mask may first be formed (step **310**). An example of a portion of an integrated circuit following step **310** is set forth in FIG **4F**. A gate mask
15 material **412** may be deposited and patterned using any of various lithographic techniques. A gate mask material **412** may generally consist of a photoresist material.

Following the formation of a gate mask (step **310**), gates can be etched (step **312**). Referring to FIG. **4G**, a portion of an integrated circuit following step **312** is set forth. A suitable etch process has been applied to remove portions of the tunnel oxide **404**, nitride
20 layer **406**, ISSG top oxide layer **408**, and polysilicon gate layer **410** that are not covered by gate mask material **412**. In one particular approach, gates may be formed by reactive ion etching.

In this manner, SONOS devices can be formed and isolated on a semiconductor

substrate **400**.

A second embodiment **300** can continue by depositing and etching a spacer layer (step **314**). An example of a portion of a semiconductor device following step **314** is set forth in FIG. **4H**. Prior to a step **314**, a gate mask material **412** may be stripped using a solvent, or etching (ashing), as but two example. Referring to FIG. **4H**, a spacer layer **414** has been formed that isolates sides of SONOS gates. A step **314** may include depositing a layer of silicon nitride, silicon oxynitride and/or silicon oxide. Preferably, a spacer layer **414** may include silicon oxide formed by chemical vapor deposition means. The layer may then be anisotropically etched to form sidewall spacers.

A second embodiment **300** may therefore result in an integrated circuit containing SONOS devices with a high-quality top oxide layer **408** that may be created with a very small thermal budget than conventional approaches that deposit a top dielectric layer.

In this way, SONOS devices may be created that offer higher performance, and/or the ability to be scaled to lower programming voltages while maintaining compatibility with conventional CMOS processes.

Referring now to FIG. 5, a wafer processing tool that may be used in the present invention is shown in a block diagram. A wafer processing tool is designated by the general reference character **500** and may include a load lock **502**, an RTO chamber **504**, and an LPCVD chamber **506**. An RTO chamber **504** may be capable of conventional dry oxidation as well as ISSG oxidation, and an LPCVD chamber **506** that may be capable of nitride deposition.

Using a tool, such as that shown in FIG. 5, a wafer may be loaded via a load lock **502**. A tunneling oxide may then be grown (step **302**) in an RTO chamber **504** using conventional

dry oxidation. A wafer may then be moved to an LPCVD chamber **506** where a nitride may be deposited (step **304**). Finally, a wafer may be moved back to an RTO chamber **504** and a top oxide layer may be grown using ISSG oxidation (step **306**). In this way, the SONOS dielectric layers may be formed with minimal movement of wafers between processing machines.

The use of single tool, as described above, may reduce defects by minimizing a wafer's exposure to external environments. Further, such an approach may simplify a manufacturing process by localizing the formation of a SONOS-type device dielectric.

It is understood that while various embodiments have been described in detail, the present invention could be subject to various changes, substitutions, and alterations without departing from the spirit and scope of the invention. Accordingly, the present invention is intended to be limited only as defined by the appended claims.